

Improvements on a Novel Hybrid Tracking System

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ABSTRACT

Today's tracking systems typically require a fixed installation in a room in order to not drift quadratically with time like common inertia measurement units. This makes tracking a delicate task in ad-hoc VR installations. To overcome this problem, this paper describes a novel hybrid tracking system and shows further algorithmic improvements to increase tracking accuracy.

CCS Concepts

•Human-centered computing → Virtual reality; Usability testing; Haptic devices;

Keywords

Electromagnetic tracking; inertia measuring unit; redirected walking

1. INTRODUCTION

For a long time, large-scale motion tracking was less important in many VR applications, since existing display technologies like CAVE or Powerwalls did not allow for walking, but used the tracking for a perspective correct stereoscopic projection. In such installations, only short range tracking was required to capture small motions like head orientation or the orientation of a 3D handheld controller.

Although it was known that real walking is superior to all other kinds of navigation in virtual environments [8], installations using real walking were rare and costly. While one group of VR installations uses locomotion devices such as the Cyberwalk setup [9], others guide the user on a curved path, such e.g. Razzaque et al. [7], Nitzsche et al. [6] or Steinicke et al. [10]. In both cases, the intention is to compress an unlimited virtual space to a physically constrained environment while still allowing the sensation of real walking. While the first group could use short range standard tracking systems, the mechanical locomotion interfaces are very challenging. On the other hand, the second group does

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not require any locomotion interface, which comes at the cost of more sophisticated long-range tracking systems.

However, typical step-in-place solutions or treadmills of the first group cannot fully provide the sensation of real walking, and thus redirection systems are gaining importance [5]. These redirection systems mainly consist of a tracking system, a head-mounted display (HMD) and a computer to render the virtual environment accordingly. Since a significant progress was made for output devices such as HMD within the past years, the remaining bottleneck is the tracking system. Here, there is still the need to install fixed installations in the physical tracking area to achieve reliable tracking results with sufficient resolution. However, this again limits the application range of such VR systems, since they are restricted to fixed installations in the physical environment and do not scale very well with the size of the tracking space.

2. RELATED WORK

An ideal tracking system should allow a real-time capturing of all six degrees of freedom with high precision, low latency and a high update rate, independent of the tracking space. For several years, this goal was followed by so-called relative tracking systems, where all references are attached to the person to be tracked. Initially, this was done with inertial sensors [1]. However, these sensors cannot really measure distances, but infer the distance by a double integration of the measured acceleration. This makes such sensors to drift quadratically with time, and thus they are not suitable to precisely measure longer walking trajectories. In order to reduce this drift, Zhang & Meng [13] use additional magnetic sensors for the heading and use the maximum vertical acceleration to estimate the step length and thus avoid the double integration. In both cases getting the head position required for real walking in virtual environments from the tracked foot is not immediately possible. A work from Hodgson et al. [3] uses inertia measuring sensors together with magnetic sensors that measure the earth's magnetic field. However, such a measurement is inaccurate in particular for an indoor use of such a system. Hamaguchi et al. [2] and Yamanaka et al. [11] use an electromagnetic tracking system together with shoe-mounted pushbuttons to detect the stance phase of the foot and the distance between the involved sensors. This principle was further extended by Zank et al. [12] to also track position and orientation of the head. The last three systems have in common that they use the standing foot as a reference, while they measure of the distance and orientation of the moving foot. For the

next step, the reference is located at the other foot that is now standing and again the distance and orientation of the moving foot are measured (see Figure 1).

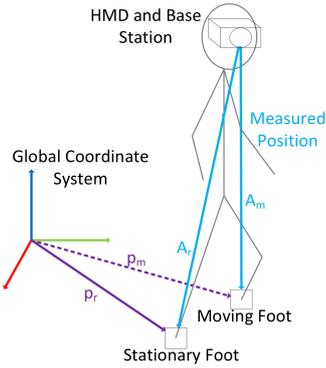


Figure 1: Hybrid Tracking System [12]

Although the hybrid systems from the above do not drift quadratically over time anymore, there is an accumulating error that linearly increases with the number of steps that are measured. While some errors come from the electromagnetic tracking system, the main source of error stems from a delayed switch of the reference from one foot to the other. Thus, the following paper will first clarify the main source of error, followed by a new proposal on how to reduce the switching latency. This will next be verified by walking experiments. Finally, the paper will conclude with a summary and outlook.

3. CONTRIBUTION

Hybrid tracking systems that sense the stance phase of human gait to dynamically switch the reference (basis) for a 6 DOF tracking system suffer from a linearly increasing error. In the next paragraphs, the main source of error will be analyzed and a new switching procedure is proposed. Our system consists of a Razer Hydra electromagnetic tracking system and two ReSense accelerometers (see [4]). The whole setup is shown in Figure 2.



Figure 2: Electromagnetic tracking system and step sensor

3.1 Error allocation

The alternating foot basis should serve as reference for the global coordinate system and thus also for the additional electromagnetic tracking system. It is obvious to use the foot that is currently in its stance phase for this reference. However, this makes it necessary to switch the basis if the foot starts moving, e.g. when it enters the swing phase. With the current system by Zank et al. [12], this switch will

take place at the end of each stance phase and the other foot will be used as a reference instead. With this procedure, it is assumed that the user is ideally walking, e.g. one foot stands still while the other one is moving. The end of each stance phase is measured - depending on the system - by shoe-mounted pushbuttons or by shoe-mounted inertia measuring units. The temporal behavior of this switching is shown in Figure 3.

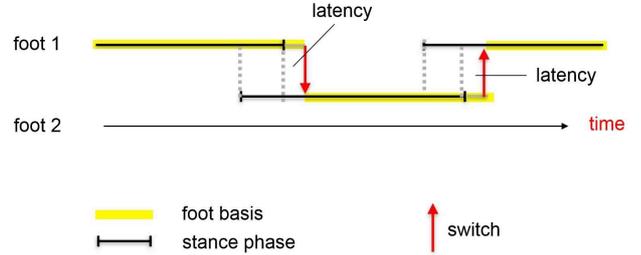


Figure 3: Temporal diagram of the current switching method

As soon as foot 1 leaves the ground (leaves the stance phase), the inertia measuring unit or the pushbutton will release a trigger to switch the reference to foot 2 that is already in the stance phase for a certain time. However, the system's inherent latency delays this trigger (see Figure 3). Thus, foot 1 is still the reference although it is already in the swing phase. The same holds true when foot 2 starts the swing phase while still being the reference. Thus, one full gait cycle evokes measurement errors from to delays in switching the reference.

As it is assumed that the reference foot stands on the ground, this "floating" reference does not only cause an error in distance measurement, but also in the orientation of the reference coordinate system (see Figure 4).

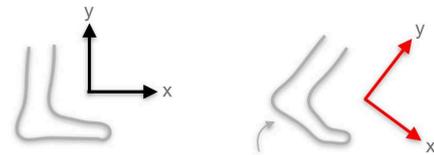


Figure 4: The latency also influences the orientation of the coordinate system

Thus, each latency interval results in an irreversible rotation of the reference coordinate system (see Figure 5).

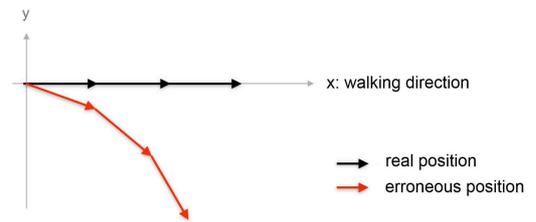


Figure 5: Increasing orientation error due to the switching latency

3.2 Improved switching algorithm

The hybrid tracking system is also able to measure the beginning of the stance phase, but so far this information is not processed any further. We thus propose to use this information to switch the reference from one foot to the other (see Figure 6).

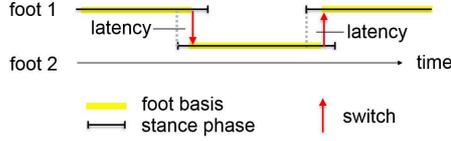


Figure 6: Temporal diagram of the proposed switching method

Within this new timing method, the "foot down" event is used to switch the reference from one foot to the other. Although the system has the same switching delay, it is avoided that a foot is still used as reference while it is already in the swing phase. Together with this new timing method, the following special use cases have to be considered:

3.2.1 Overlap of swing phases

In human locomotion, e.g. when running, it can happen that both feet are in the swing phase (see Figure 7).

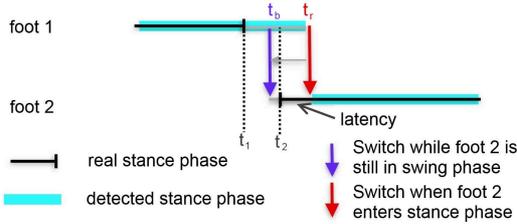


Figure 7: Stance phases do not overlap

If the new switching procedure would be applied to this case, the overall delay would be (see Figure 7).

$$t_{delay} = t_2 - t_1 + t_{lat} \quad (1)$$

It is thus longer than the old switching method, which would result in $t_{delay} = t_{lat}$. It is obvious that for this case, the new switching method should be applied, since for this situation the old switching method would perform better. Thus, our new method also allows a detection of such gaits that require applying the old switching method.

3.2.2 Non-alternating walking behavior

Non-alternating walking behavior could occur at short stops during walking, when the user starts walking again with the same foot that hit the ground last. However, with the new switching model introduced above, this foot still would be the reference although it is in the swing phase after continuing to walk (see Figure 8b). Thus, the switching method was extended in such a way that it checks for alternation. If this does not occur, it automatically switches to the non-moving foot (see Figure 8c).

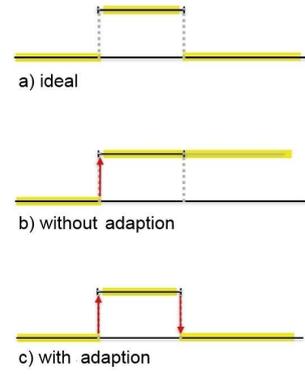


Figure 8: Extension of the new switching model for non-alternating walking behavior

3.2.3 Wrong gait detection by the sensors

Due to measurement errors or wrong walking patterns it might happen that one foot is detected to be in the stance phase although it is not. In order to avoid this problem, the algorithm also checks for the duration of the detected stance phase. Only if the detected stance phase exceeds a certain temporal threshold, the reference will be switched (see Figure 9). Although this introduces an additional latency to the system, it significantly reduces errors due to noisy sensor signals.

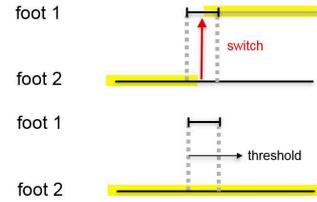


Figure 9: Verification of the minimum stance time to avoid wrong switches of the reference

4. ANALYSIS OF THE MODIFIED HYBRID TRACKING SYSTEM

The modified tracking system was compared to the old autonomous tracking system. When walking on a straight line, the old switching method (see Figure 10, top) was compared to the new switching method (see Figure 10, bottom). In both plots, the foot currently used as reference is visible as a rectangular signal, which determines the switch of the reference point from one foot to the other. The red line represents the base's movement along the walking direction, while the blue and green line represent movements in upwards and sideways direction respectively. The dotted line is the reference tracking information, measured by an Intersense IS-1200 optical tracking system. Since the system uses dead-reckoning, the initial position and orientation is adapted to match the IS-1200 reference measurement for better comparability.

It can be seen that the improved version follows much longer the ideal walking path, although there is an accu-

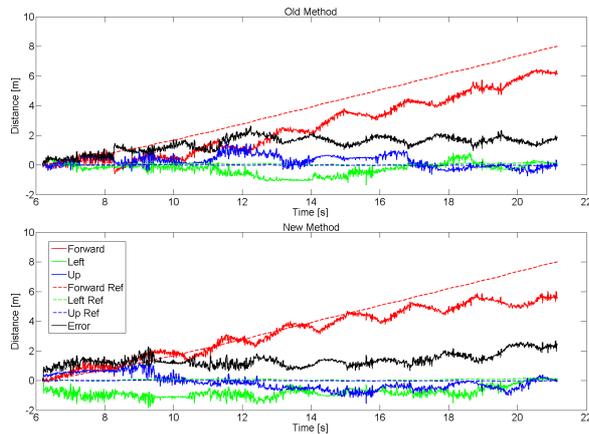


Figure 10: Comparison of the old autonomous tracking system with the improved version

mulated error as expected. This error (visible as black measurement signal in Figure 10) mainly stems from two sources: the measurements noise of the electromagnetic tracking system, and a measurement error coming from the motion of the reference foot.

As all electromagnetic tracking systems, also the employed Razer Hydra suffers from metallic material in the tracking range, or from electromagnetic sources in the close neighborhood. The proximity of the sensors next to each other as well as to the step detector with the Bluetooth link causes additional noise.

The step detector is attached to the foot (the heel) to detect the stance phase and to switch the reference basis correspondingly. However, the roll motion of the foot also causes a slight movement of its physical position, and thus also a drift of the reference point. Consequently, the measured distance is shorter than the actual step length, resulting in a smaller slope of the red measured signal with regard to the actual distance (see Figure 10). The system is designed for regular walking, since it always needs one foot touching the ground. Thus, a condition like running is not supported.

5. CONCLUSIONS

In this paper, we showed an improvement of an autonomous tracking system based on accelerometers and an electromagnetic tracking system. The user studies then showed that the new system performs better and approaches an ideal absolute tracking.

Future work will mainly focus on the integration of improved hardware like the STEM electromagnetic tracking, which will hopefully reduce noise in the acquired signal. Moreover, we will also implement additional filtering algorithms to reduce noise, and finally also the slight movement of the basis based on the foot's roll motion will be considered. Finally, we will also evaluate the long-term accuracy of the system, when users will walk for several minutes in a virtual environment.

6. ACKNOWLEDGMENTS

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